An Improved Three-Channel Carrier Telephone System

By J. T. O'LEARY, E. C. BLESSING and J. W. BEYER

This paper describes an improved three-channel carrier telephone system for use on open-wire lines. It employs recent advances in the telephone art to bring about many economies and circuit simplifications as compared with previous models of the three-channel system. A new type of automatic regulating equipment is included.

Introduction

THERE are now in service in the Bell System approximately 750,000 miles of telephone circuit which are furnished by carrier systems. Of this total, almost 90 per cent is provided by some 600 Type C systems, ranging from about 75 miles to over 2000 miles in length. Basically designed to add three carrier channels to the normal voice channel on open-wire lines, the Type C system has also been used in special cases to provide additional circuits over deep sea cables of moderate lengths.

The system was first described in this Journal in the July 1928 issue.[1] Improved designs and the application of new circuit elements have recently permitted a very extensive revision of the terminal and repeater equipment which results not only in striking reductions in size and cost as compared with the older equipment, but also gives a considerable improvement in transmission performance. A new type of automatic regulating equipment has been provided for both the terminal and repeater.

The improved system employs heater type pentode tubes, copper-oxide modulators and demodulators and makes use of the negative feed-back type of amplifier at both terminal and repeater points. The terminal band filters are newly designed to give improved transmission frequency characteristics on all channels. Each channel is arranged to terminate on a four-wire basis in the same manner as the Type K system for cables.[2]

An outstanding feature of the modified design is the large saving in space in comparison with the previous equipment. As shown on Fig. 1, the complete terminal with its regulating equipment occupies a single bay, whereas the older system without regulating equipment required two and one-half bays. The repeater space savings, while not so large, are nevertheless substantial. The number of vacuum

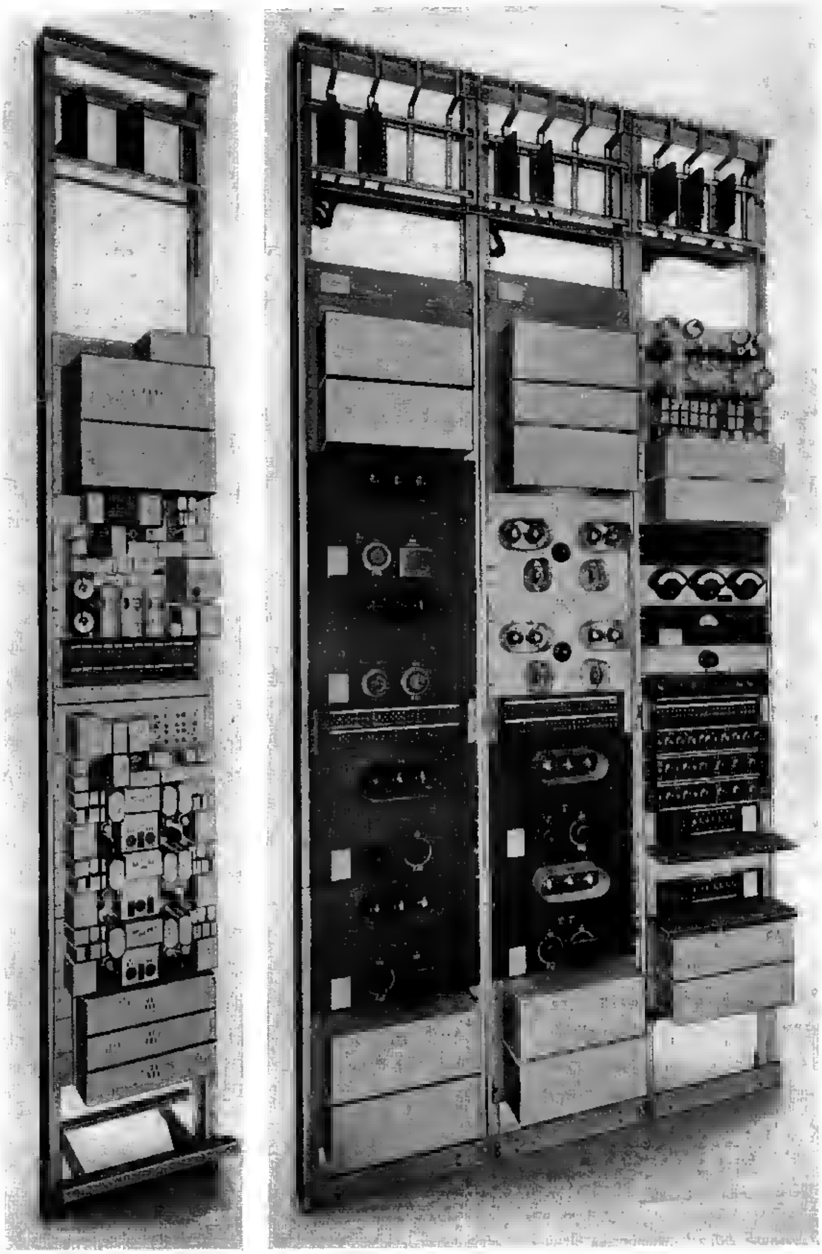

Fig. 1—New and old type C carrier telephone terminals.

tubes required in the system has been reduced, which results in a material saving in power.

Certain features of the improved equipment, notably the automatic regulation, can also be used on the older types of systems and the design objectives were set up with this in view.

Frequency Allocation

The frequency range employed by the system and the allocation of channel bands within that range are shown in Fig. 2. The allocations used in the older systems are also shown for comparison.

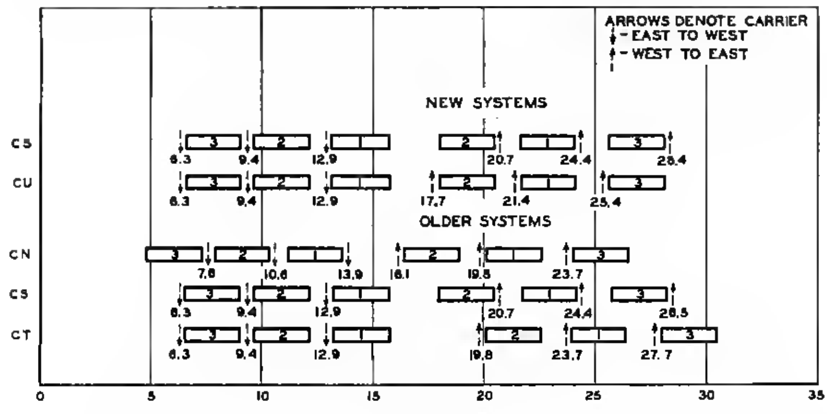

Fig. 2—Frequency allocation of the new systems relative to that of the older systems.

The original selection of the frequency range for the Type C system was the result of many different factors. Foremost among these was the desire to keep the frequencies low in order to minimize line crosstalk and attenuation and changes in the latter due to weather and temperature. On the other hand was the greater filter cost that results from crowding the channels close together. Different frequency bands were used for transmitting in opposite directions in order to avoid the problem of near-end crosstalk and to give the advantages of four-wire transmission. Although consideration was given to the general desirability of increasing the band of frequencies effectively transmitted by the individual channels, the requirement for coordinated operation with older systems already in use precluded any material increase in the frequency space allocated to each channel of the new system. Nevertheless, as will be seen from Fig. 4, the channels show very little distortion within the transmitted band and represent a material improvement over the older systems.

Because the line crosstalk tends to be greater at the higher frequencies, past experience has indicated the advantage of having available two systems between which the crosstalk in the higher frequency group will be unintelligible. Two allocations are provided for this purpose, designated CS and CU. The channel bands are identical in the lower frequency group (East to West) and in the upper frequency group (West to East) differ only in that the carrier frequencies are at opposite ends of the bands. In this group crosstalk between similar bands will have the speech frequencies inverted and will therefore be unintelligible.

This arrangement does not give as high a crosstalk advantage as the arrangement used previously where the bands were not only inverted but also displaced with respect to each other. However, better line crosstalk conditions now prevail due to the application of improved transposition designs and line configurations to the more recently constructed lines and to the use of new methods of mitigating crosstalk on the older lines. This permits the simplification of the frequency allocation, as a result of which one system may be readily converted into the other with fairly simple equipment changes. It will also be possible to use the voice frequency circuit on all pairs as a program circuit transmitting up to 5000 cycles. The advantages of the greater plant flexibility resulting from these two factors are obvious.

The new system may be used on suitably transposed lines with the Type D [3] and Type H [4] single channel systems, whose frequency bands are such that no serious near-end crosstalk problem will arise.

Overall System

A block diagram of a complete system, consisting of the two terminals and a single intermediate repeater, is shown on Fig. 3. In practice there might be as many as ten or more such repeaters. The two terminals differ from each other only in the frequencies for which their respective transmitting and receiving circuits are designed. The west terminal transmits the high-frequency group of Fig. 2 and receives the lower frequency group while the east terminal does the reverse. The repeater is provided with means for separating the frequencies in the two directions of transmission, amplifying the current to the desired level, and passing them on to the next line section.

A typical overall frequency characteristic for one of the circuits derived from the new system is shown on Fig. 4. This characteristic illustrates the relative freedom from distortion in the transmitted frequency range.

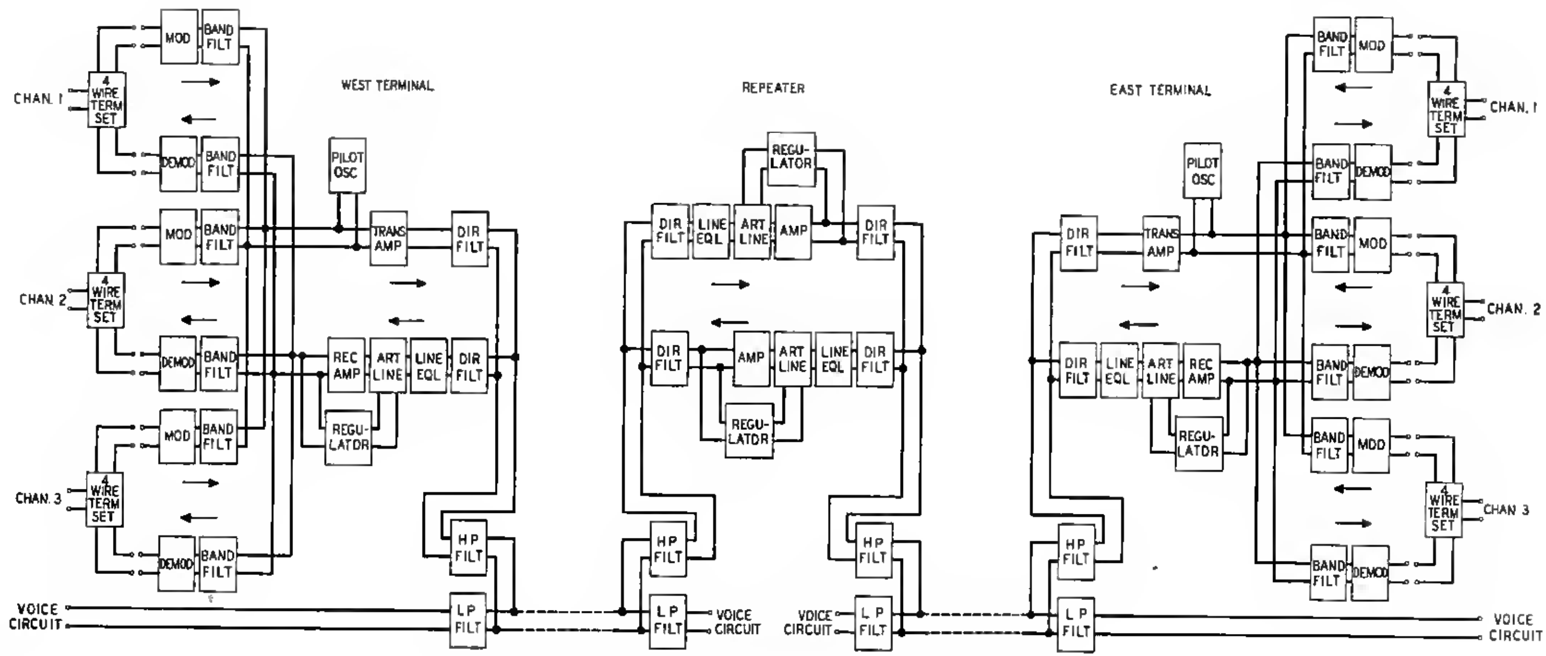

Fig. 3—Schematic of an overall system with one repeater.

The carrier channels are separated from the voice frequency circuit on the same pair of wires by means of a high-pass and low-pass filter combination as shown on Fig. 3. Several different filter sets are available for this purpose differing from each other in the frequency

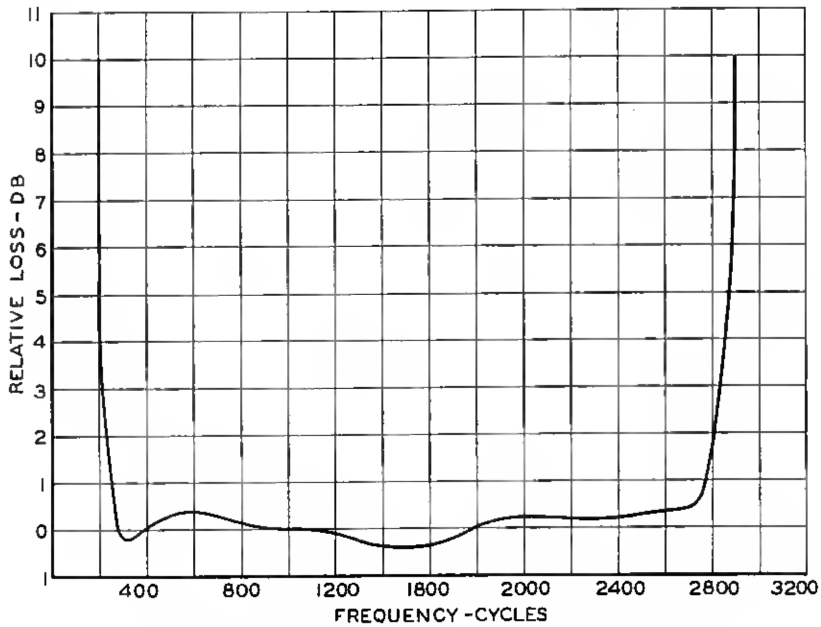

Fig. 4—Typical overall transmission-frequency characteristic.

band which is desired in the voice circuit. Where the voice circuit is an ordinary message circuit the filter will have a cutoff around 3 kc. Where it may be used for program transmission a filter set having a cutoff above 5 kc is provided. For still wider program bands there is a filter set cutting off above 8 kc. The use of this latter filter would, of course, require the sacrifice of the lowest carrier channel since it would be overlapped by the program band.

An important feature of the system is the method of stabilizing the overall transmission. Ahead of the terminal transmitting amplifier in each direction of transmission there is connected to the circuit an oscillator which generates a pilot current. This pilot current has a frequency adjacent to the band of the middle channel. The oscillator is designed to have a relatively high degree of stability with respect to output and frequency. At the output of each repeater and at the receiving terminal the pilot frequency is selected by a high-impedance bridging filter, which has little effect on the through transmission,

and is then used to actuate a regulating mechanism. Changes in the line transmission at this frequency are indicative of the changes at all frequencies and the regulator functions to maintain a nearly constant output level in all three-channel bands.

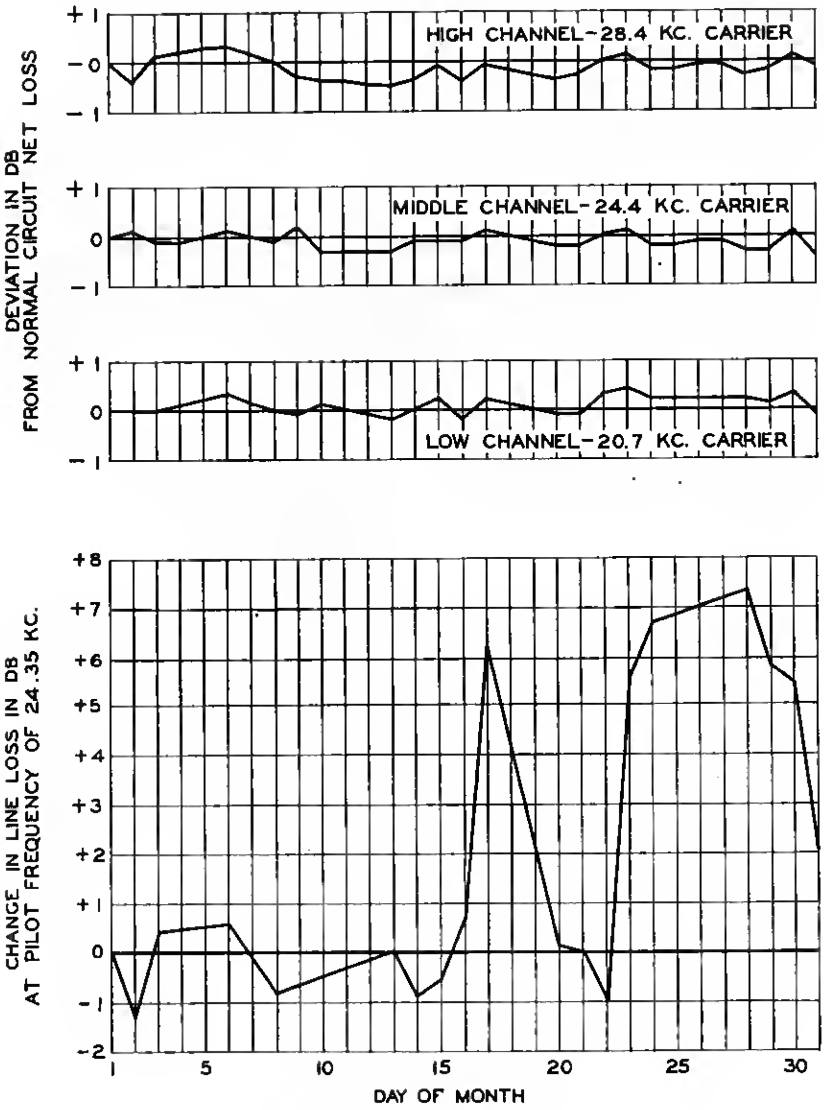

Fig. 5—Chart showing regulation for a period of one month on system with one repeater.

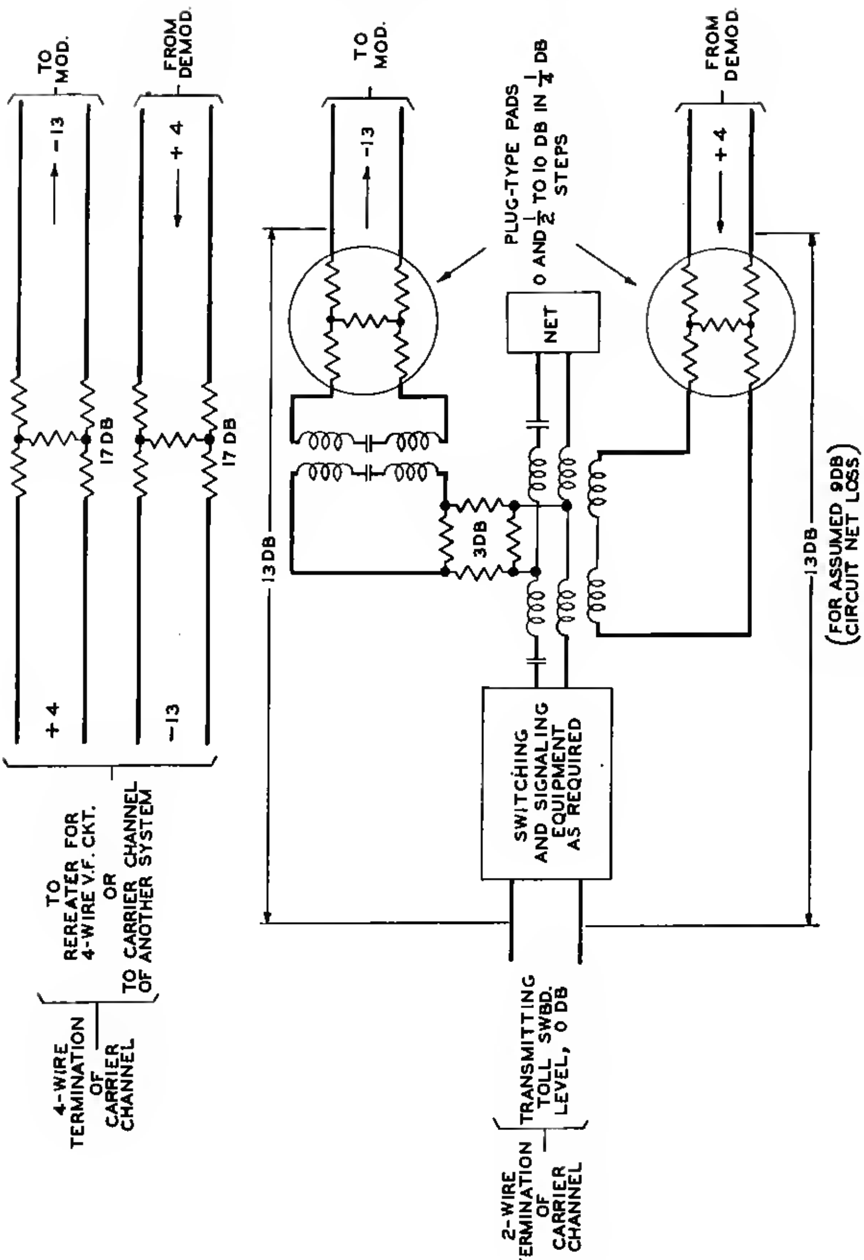

Fig. 6—Voice terminating arrangements.

The pilot current is also used to indicate through an audible or visual alarm any trouble which results in large sudden changes in transmission such as would be occasioned by an open or short circuit on the line itself.

The ability of the regulating mechanism to stabilize the transmission over the system is shown on Fig. 5 which shows the deviations recorded in daily measurements on all three channels of a 250-mile system over a period of one month. The actual changes in line loss at the pilot frequency are also shown for comparison. During this period various conditions of temperature, rain and fog were experienced.

With the transmitting level that has been provided and for ordinary line conditions it is found practicable to employ repeater spacings of from 125 miles to over 250 miles. The exact distance in any particular case depends upon many factors, such as: wire size, length of toll entrance or intermediate cables, location of existing offices and the susceptibility of the line to sleet or frost. Where this latter condition is prevalent conservative spacings are desirable.

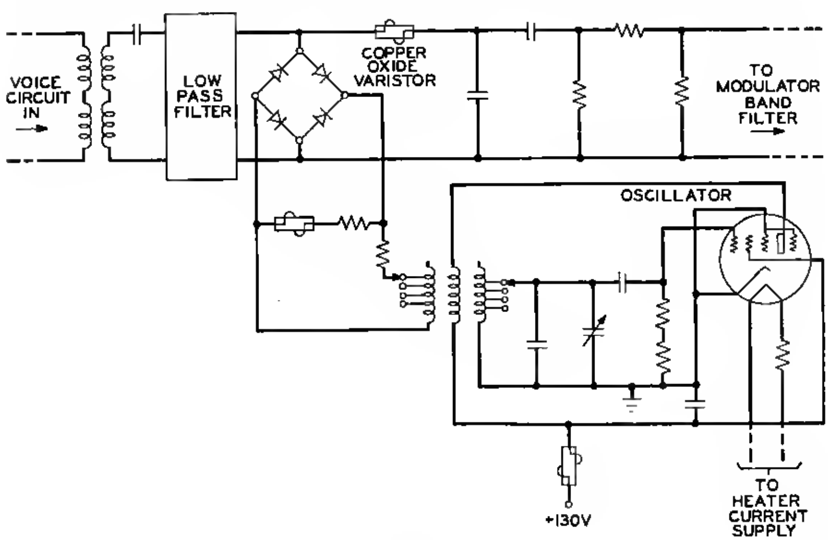

Fig. 7—Schematic of modulator.

Terminals

The general theory of operation of the terminal may be understood from the block diagram shown in Fig. 3. On the voice-frequency side each channel terminates as a four-wire circuit. The input to the carrier system from the voice circuit is designed to operate at a level

13 db below the transmitting toll switchboard which is the common reference point. The output from the system is at a level 4 db above that point. Equipment for coupling the system to both two-wire and four-wire circuits has been designed. The circuits employed in each case may be seen in Fig. 6.

The modulator circuit, shown in Fig. 7, uses copper-oxide varistors [5] for converting the voice frequencies to the higher line frequencies. The high degree of balance obtained in the copper-oxide varistors has the important advantage of making carrier leak a practically negligible factor. This is of particular importance in the case of that channel to which the pilot current is adjacent in the frequency spectrum. The modulator circuit is also designed to limit the peaks of very loud talkers which would otherwise overload the common amplifiers. The effect of this limitation on the quality of the speech transmitted is not noticeable.

The oscillator which supplies the carrier to the modulator is designed to be stable in both output and frequency. When it is once adjusted with the oscillator at the distant end, departures from synchronism will be relatively small. Part of this stability is due to a new circuit design employing coil and condenser elements having opposite temperature coefficients so that changes in one will be compensated for by changes in the other.

The band filters use coils wound on magnetic core material, having improved modulation characteristics, instead of the solenoidal air core coils previously used. This results in a considerable reduction in the space which they occupy.

The transmitting and receiving filters associated with each channel are identical as to band width. They are further characterized by a more abrupt increase in discrimination immediately below and above the pass-band frequencies than was realized in the channel filters for the previous Type C systems and also by less distortion across the pass band. Most of this distortion is in the form of higher loss in the vicinity of the band limiting frequencies. It was deliberately included in the design of the filters for the purpose of masking delay distortion effects on overall transmission quality which might otherwise become noticeable when four or five type C carrier telephone systems are connected in tandem.

The uniformity and symmetry of the various filters are shown by Fig. 8 which gives the characteristics of those in the upper frequency group. This symmetry is required in this group in order to make the CS allocation convertible into the CU by moving the carrier from one end of the band to the other.

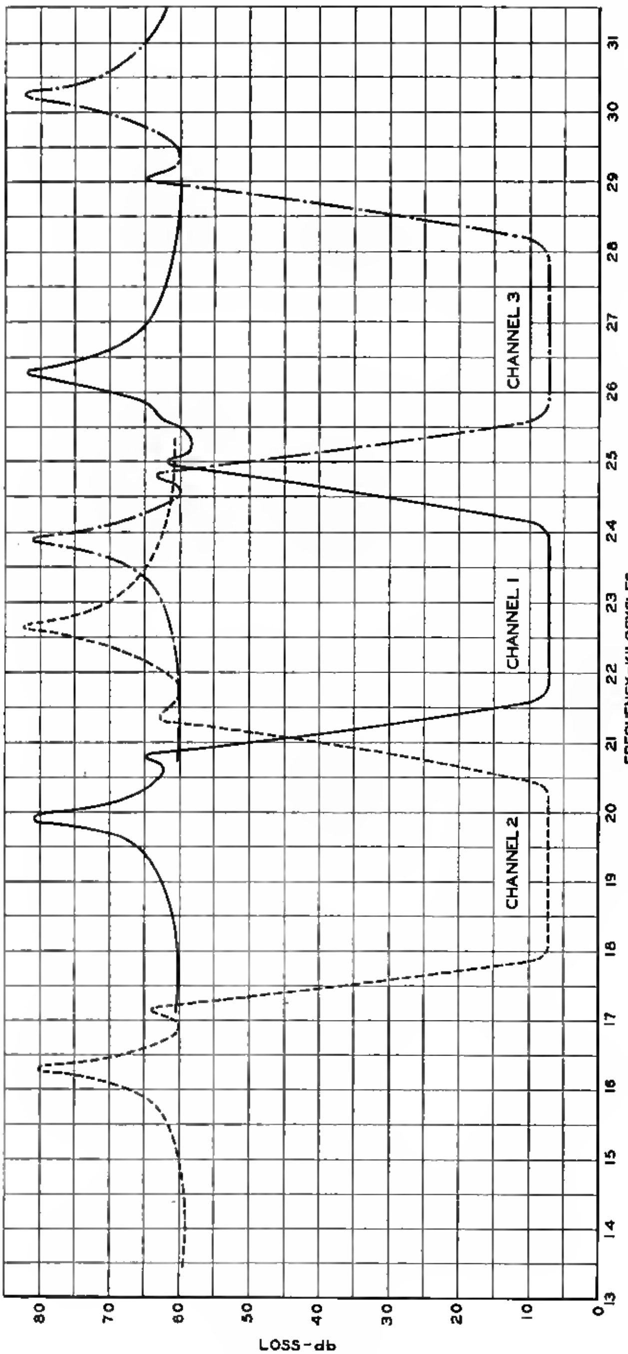

Fig. 8—Typical channel band filter characteristics.

The transmitting amplifier is the same as that used on the receiving side and in both directions of transmission in the repeater. This amplifier is capable of operating at a level 18 db above the transmitting toll switchboard.

On the receiving side, following the directional filters, is the equipment which makes up the system of equalization and regulation. This is identical with that used at the repeaters and is described more fully later. The regulator functions so as to maintain a nearly constant level at the output of the receiving amplifier. The band filters differ from those on the transmitting side only in the frequency bands which are transmitted and are the same as those used at the distant transmitting terminal. The demodulator circuit is of the same general type as the modulator circuit and the oscillator which supplies it with a carrier frequency is practically identical to that used by the modulator. However, because of the low levels at which these copper-oxide units are operated, an amplifier tube is necessary to restore the level to the required value at the output. The gain of this amplifier is continuously adjustable over a range of about 10 db so that precise adjustments of the overall circuit net loss can be made on each channel individually.

On very short non-repeatered systems the transmission variations may not be great enough to require the automatic regulating equipment. In such cases a manually operated potentiometer will be used for controlling the gain.

Repeater

A block diagram of the repeater is shown in Fig. 9. Directional filters on each side separate the two directions of transmission. As in the case of the receiving terminal, the equalizing and regulating equipment maintains all channels at the proper level at the amplifier output. The high cut-off filter shown on the circuit in the west-to-east direction limits the transmission to frequencies below 30 kc. This may be desirable when a system employing still higher frequencies is used on the same pair as the Type C system or on other pairs on the same line.

The repeater provides a maximum gain of about 49 db at the highest frequency in the upper group of the new system and about 43 db at the similar point in the lower group. The exact gains at different points in the frequency range are adjusted by the regulator so as to compensate for the attenuation of the line section preceding the repeater.

A complete repeater with its regulating equipment is mounted on a single equipment bay. A photograph of this bay is shown in Fig. 10.

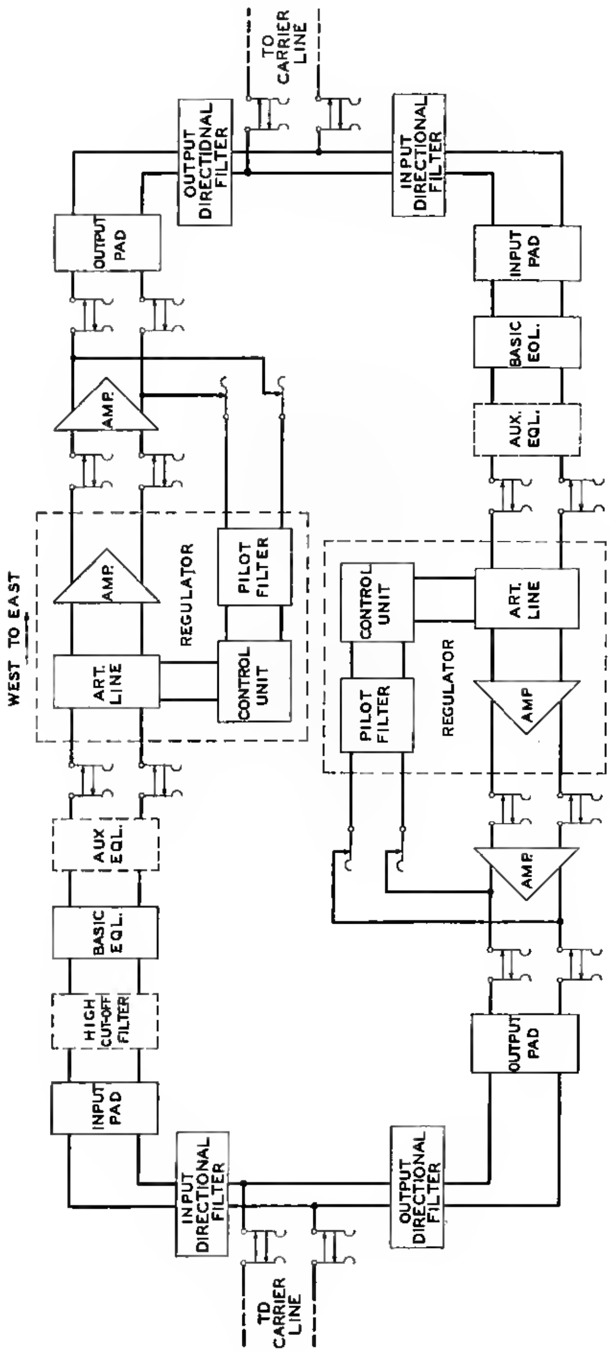

Fig. 9—Schematic of carrier repeater.

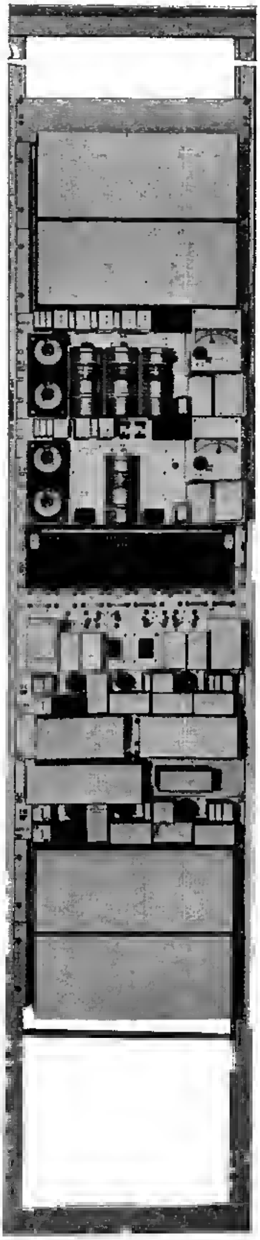

Fig. 10—New repeater for Type C systems.

Regulation

At the transmitting terminal each channel is adjusted to the same output level and in the operation of the system it is desirable to restore this equality of levels at each repeater point and at the receiving terminal. In each direction of transmission the line losses at the upper end of the frequency range will be higher than at the lower

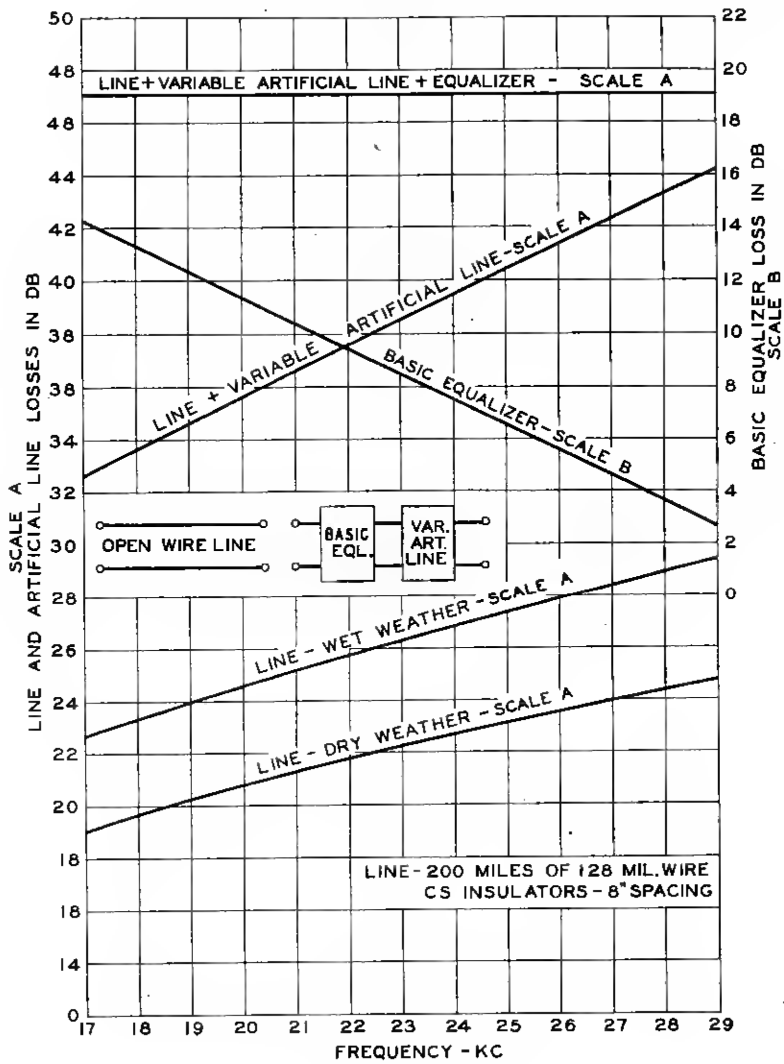

Fig. 11—Theory of regulator.

end and, furthermore, these losses change by varying amounts with temperature and weather conditions. It is the function of the regulating equipment to provide the needed adjustment and equalization of levels over the wide range of line conditions.

The theory of the operation of the regulating system is shown in a simplified manner in Fig. 11. The line circuit is connected at the end of each repeater section to a line equalizer, which is in turn connected to an artificial line unit designed to be continuously variable. The slope of the line equalizer loss characteristic is the reverse of the line slope and is as great as may be found in practice on any ordinary length of line section except under conditions of severe ice or frost. The artificial line slopes in the same direction as the line circuit itself. In lining up a system the artificial line is adjusted so that when added to the real line the slope of the combination neutralizes that of the equalizer leaving the overall transmission very nearly uniform for all frequencies in the range. Then as the loss and slope of the real line change, the artificial line is made to change in the reverse direction leaving the overall transmission still uniform. The action of this artificial line is under the control of the pilot current, referred to before, and the design of the equipment is such that in maintaining the pilot at the proper level the other channels are also properly adjusted.

In practice, the regulating unit must take care of a wide variety of wire sizes, wire spacings and insulator types. It has been found, however, that the change in slope for a given change in attenuation at some reference frequency is very nearly the same for all combinations of the above during ordinary weather conditions. As a result a single unit can be made to serve all cases.

Where conservative repeater spacings are employed there is a large amount of regulating range available to take care of sleet or frost formations on the wires. For the particular use illustrated in Fig. 11 the total range is about twice that required for ordinary wet weather. For shorter sections the available range would be still greater.

Some details of the regulating equipment are shown on Fig. 12. The pilot frequency is selected from the other frequencies on the line by a narrow band filter bridged across the output of the amplifier. This filter has a high impedance so that the bridging loss is small and does not interfere with regulation at succeeding stations.

A copper-oxide varistor is used to convert the selected pilot frequency into direct current which in turn actuates two Weston Sensitrol relays connected in series. The relays are equipped with meter scales on which a needle attached to the armature serves as a pointer. One of these relays controls the action of the regulator, the other functions

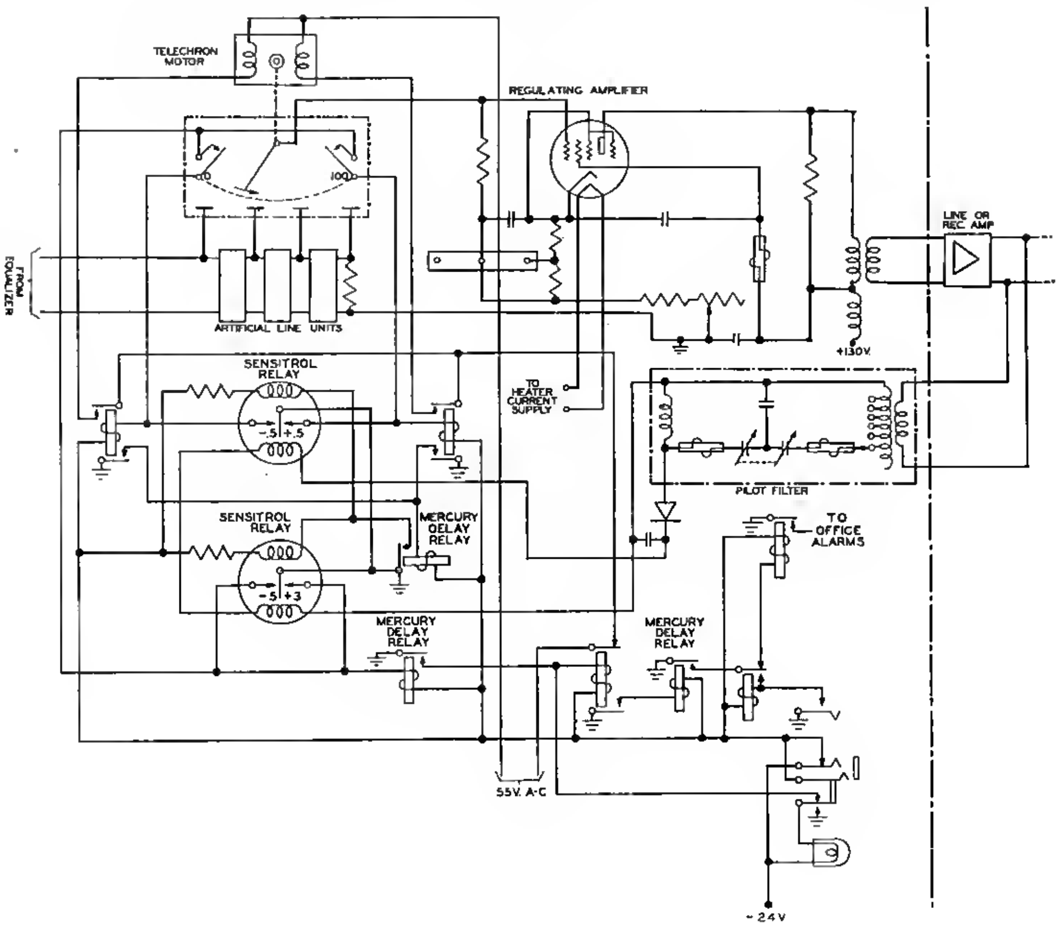

Fig. 12—Regulator circuit.

in an alarm circuit described later. With normal current flowing, corresponding to the proper pilot level at the output of the amplifier, the pointers of these relays are on midscale with a reading of 0 db. When the pilot level changes by more than .5 db in either direction, contacts close on the relay controlling the regulator and cause power to be supplied to a Telechron motor which controls the continuously variable artificial line mentioned above. This will be driven intermittently at a rate of about 1 db per minute until the output level has been restored to within ± .5 db.

As will be seen from the sketch the variable line consists of three sections connected in tandem. The ends of these sections are connected to the four stators of a variable air condenser. The rotor of

the condenser meshes with any stator or with parts of two adjacent stators. The condenser, therefore, serves as a potential divider across the regulating network sections, the loss introduced depending upon the position of the rotor with respect to the stators. Basically these artificial line sections consist of units having the same loss characteristic. The first section, however, may be supplemented by additional units which will be required on the shorter line sections in order to build out the line slope as shown on Fig. 11. Since this section will be the last one to be cut out by the regulator, the less accurate part of the regulating range is thereby reserved for the periods of very high line loss, such as during ice or frost formation which occurs only infrequently.

The second sensitrol relay has contacts which close only on much larger changes in the pilot level such as would result from a failure of the line itself. When it operates it disables the regulating circuit and through a slow operating mercury relay brings in an audible or visual alarm indicating to the attendant that the system is in trouble. The slow operating relay introduces a delay in the operation so that short interruptions will not operate the alarm system.

The principal function of the regulating amplifier shown on Fig. 12 is to provide a high-impedance termination for the regulating network and condenser combination. There is, however, a small amount of gain available which may be useful in some cases.

New Line Anplifier

The amplifier which is used in the repeaters and in the transmitting and receiving branches of each terminal is one of the outstanding developments of the system. It was designed to have satisfactory transmission characteristics over both upper and lower frequency groups. It employs the principle of negative feedback [6] to achieve a high degree of stability, freedom from modulation and stabilized input and output impedances.

The advances made in the design of this amplifier can be seen by the comparison in the following table with the push-pull amplifier which was used in the older systems. In some cases the latter was supplemented by an auxiliary amplifier where higher gains were needed.

	24-Volt Power—Watts	130-Volt Power—Watts	Panel Space—Inches	Gain db	No. of Tubes
Push-Pull Amplifier	52.8	15.1	12¼	32	6
Push-Pull Amplifier Plus Auxiliary Amplifier	76.1	17.2	17½	48	8
New Feedback Amplifier	16.4	6.3	3½	50	2

There should be added to the comparison the fact that the new amplifier does not require selection of tubes to obtain satisfactory modulation results. It is also more stable with variations of power voltages and changes of vacuum tubes. The large space saving will be evident from Fig. 13, which pictures the new amplifier with the old push-pull amplifier and its auxiliary.

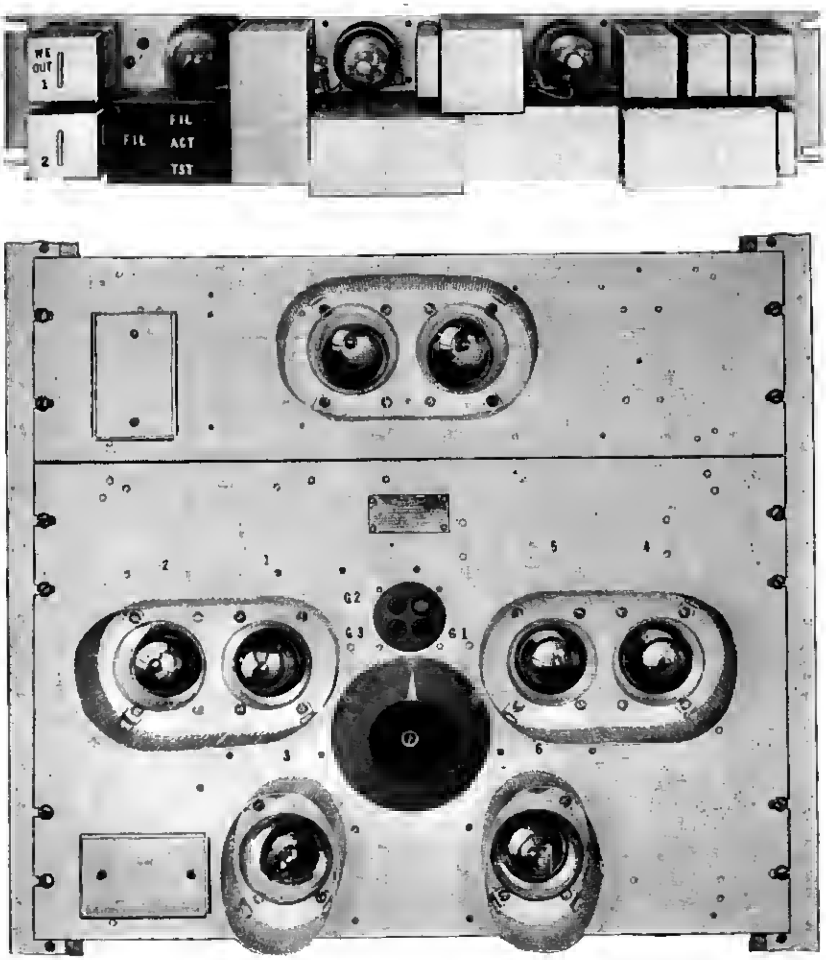

Fig. 13—New amplifier compared with the older type which it replaces.

The circuit of the amplifier is shown in Fig. 14. It is a two-stage circuit using pentode tubes. As will be seen from the circuit the feedback connection is obtained through the use of input and output transformers which are essentially hybrid coils. These coils are

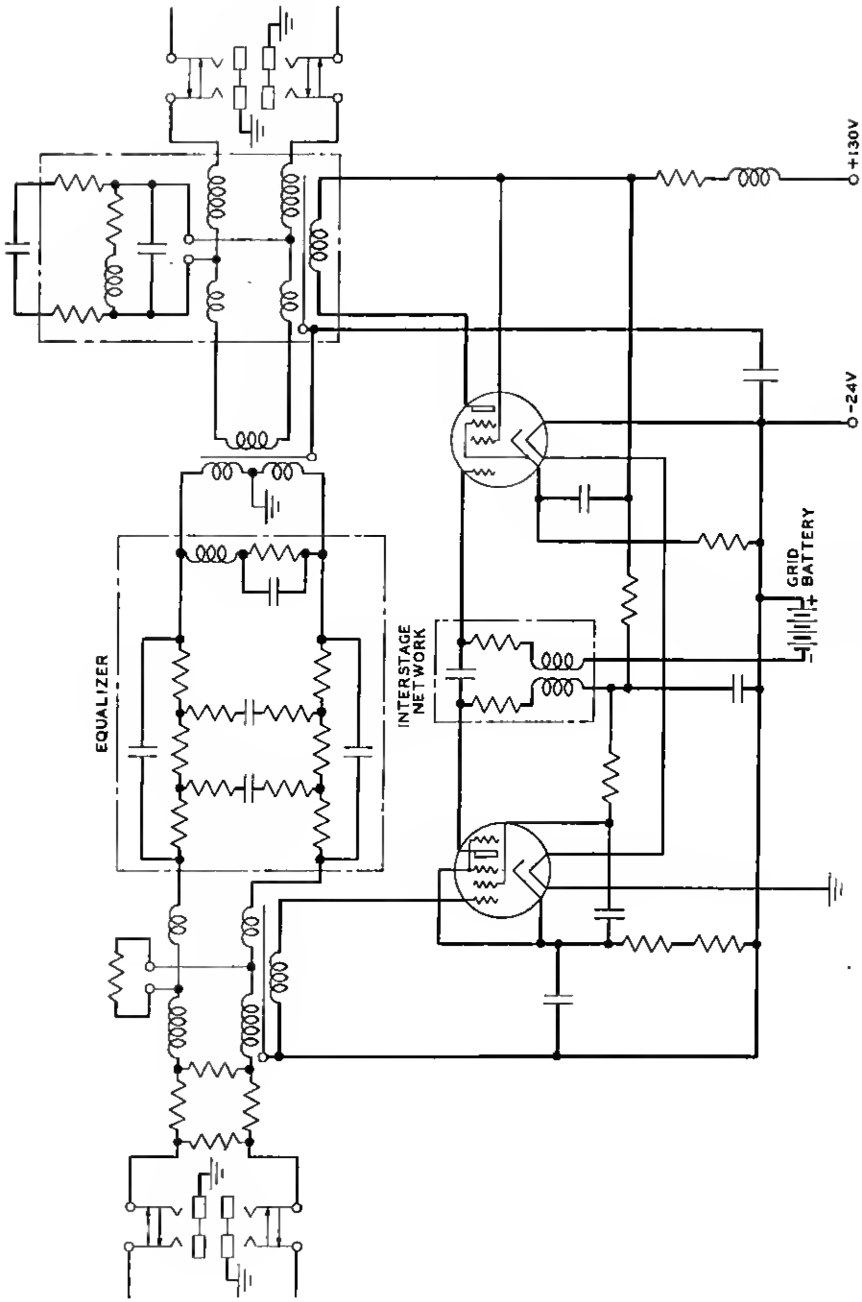

Fig. 14—Schematic of amplifier used in terminal and repeater.

designed to have unequal ratios, minimizing the loss to through transmission at the expense of greater loss in the feedback circuit. Including the transformers in the feedback path makes them also beneficiaries of the feedback with a resultant reduction in impedance irregularities, transmission distortion and modulation products.

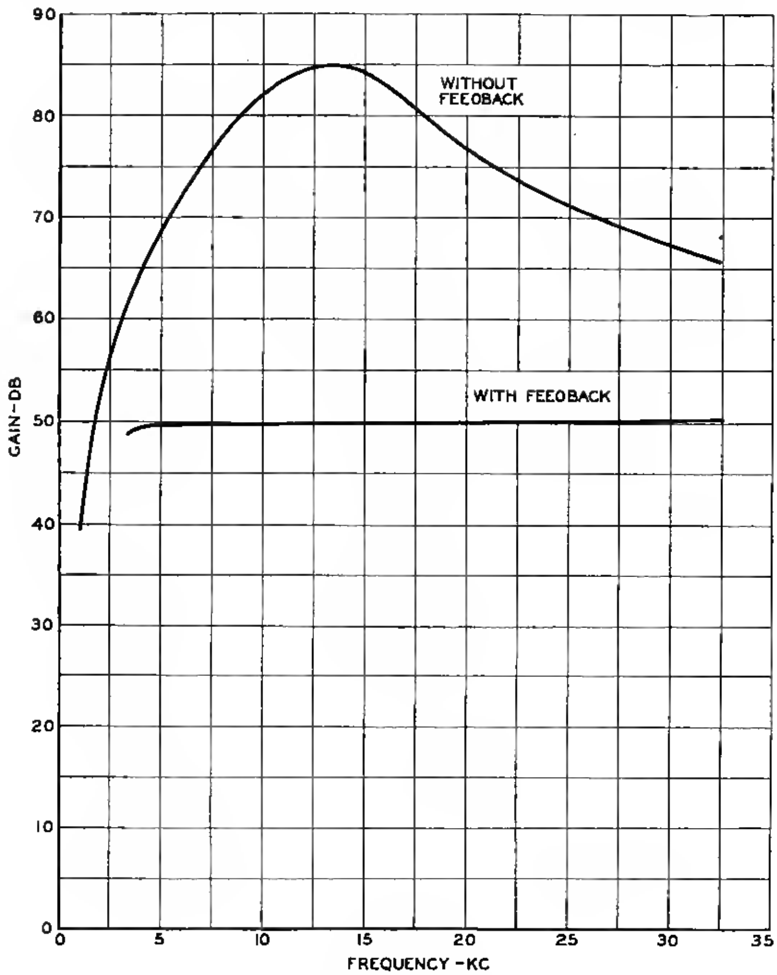

Fig. 15—Gain frequency characteristic of amplifier.

The amplifier has a gain of 50 db with provision for increasing it to 52 db when used as a terminal transmitting amplifier. Gain-frequency characteristics are shown in Fig. 15 for the 50-db gain condition with and without the feedback connection. The effect of feedback on transmission distortion is evident in this figure.

The second and third harmonic products in the amplifier are illustrated in Fig. 16 which shows their relation to the fundamental for different values of fundamental output. This harmonic production is a good measure of the modulation performance. In this respect

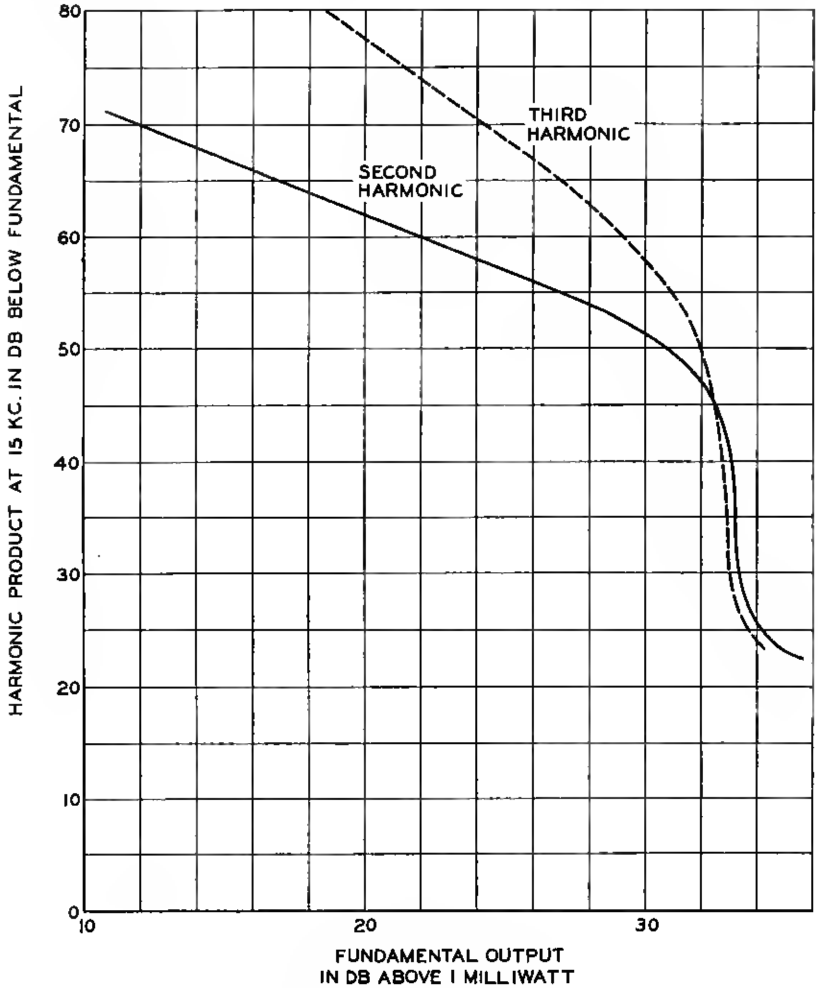

Fig. 16—Modulation in line amplifier.

the new amplifier is as good as or better than the push-pull amplifier which was used in the older system when a periodic selection of tubes was necessary to insure a satisfactory reduction of second harmonics.

A gain-load characteristic of the amplifier, with respect to a single-

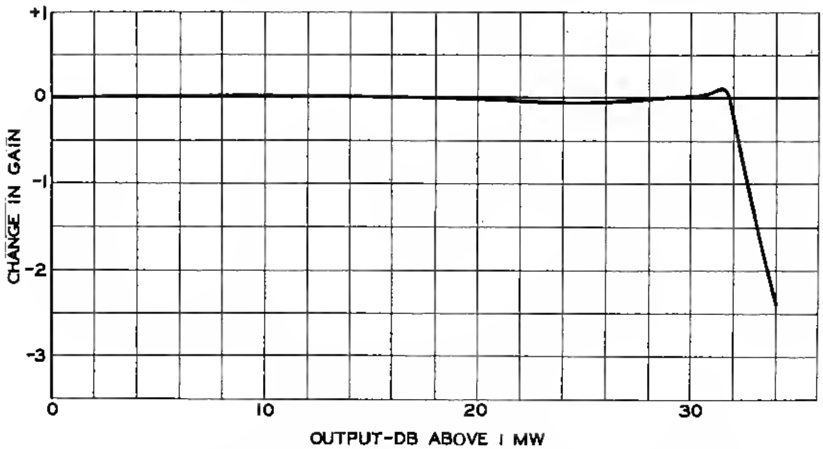

Fig. 17—Gain-load characteristic of amplifier at frequency of 15 kc.

frequency output, is shown in Fig. 17. Translated into terms of three-channel operation this means a permissible level of 18 db above the transmitting toll switchboard without noticeable distortion or interference between channels due to modulation.

Power Supply

The new system is designed to operate at both terminals and repeaters on standard telephone office battery supply of 24 and 130 volts. A dry-cell battery is required to supply grid bias to the output tube of each amplifier. A small amount of 110-volt a-c power is also required to drive the Telechron motor in the regulator circuit. The total steady power consumption in a terminal is 88 watts and in a repeater is 56 watts. These figures compare with 220 watts and 164 watts, respectively, in the older terminal and repeater.

Where regulated 24-volt battery is not available, tubes having a slightly greater current consumption are used in combination with ballast lamps. In this case the power used will be somewhat greater.

Provision has been made for a separate a-c power conversion unit to be used with the system in offices where the usual d-c voltage is not available. This should prove of great value where the provision of a battery reserve is not warranted.

Signaling

Standard voice-frequency signaling equipment can be used with the new terminals. There is also available a new type of ringer circuit in which a single tube functions both as the source of power for an outgoing signal and as a detector for an incoming signal. This

circuit employs heater type tubes and will operate from the a-c power conversion unit mentioned above. Since it also obviates the need for a 1000-cycle generator as a source of signaling current it is particularly well adapted to the small office type of installation.

Equipment Features

As mentioned before the new terminal is much more compact than those previously used. Formerly $2\frac{1}{2}$ bays of standard size were required for the terminal proper and an additional bay for the automatic regulating equipment. Now a complete terminal including the regulating equipment can be mounted in one such bay with some space left for miscellaneous equipment.

The same degree of compactness has been applied to the new repeater. A bay of standard size was formerly required for the repeater proper with another bay for the automatic regulating equipment when provided. Both are now provided in one bay and, as in the terminal, some space is available for mounting other equipment.

The assembly of the equipment panels of the carrier terminal and repeater generally follows conventional practices, the repeating coils, condensers, vacuum tubes, etc., being mounted on the front of steel panels with the electrical terminals projecting through and the wiring placed on the rear. The filters are in sealed cans with soldering terminals brought out on the rear for wiring connections.

In view of the wide field of use anticipated for the new system, somewhat more than the usual flexibility of assembly and arrangement of parts has been provided. In small terminal offices, that is, offices having one or two systems, the four-wire terminating sets and associated patching jacks and the carrier line equipment and associated jacks may all be in one bay, using for this purpose the miscellaneous bay space referred to above. Similarly, the line filter equipment may be mounted on the repeater bay.

In the larger terminal offices, in order to facilitate operation and maintenance, the four-wire voice-frequency patching jacks can be located in a central patching bay with similar jacks from other carrier channels. Testing and monitoring equipment provided at such a point will, therefore, be common to many circuits. In the same manner the carrier frequency patching jacks of a large number of terminals or repeaters in an office can be grouped at a central point.

Line Considerations

Since the new system occupies practically the same frequency range as its predecessor, it can be applied to open-wire routes in very much

the same manner. Wire sizes of 104 mil, 128 mil and 165 mil are commonly used in the Bell System plant, the particular size often being governed by mechanical rather than by transmission considera-

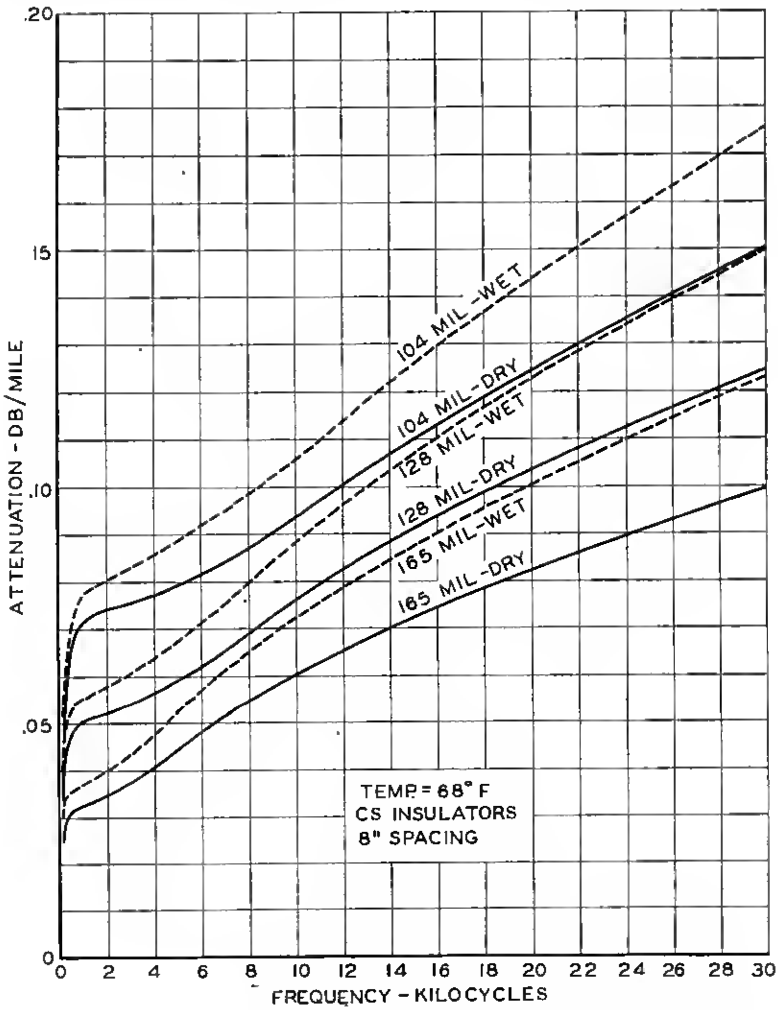

Fig. 18—Attenuation characteristics of 104, 128 and 165 mil open-wire lines.

tions. These lines are carried into the terminal and repeater offices through cables which are usually loaded to maintain smooth impedance relations and reduce the transmission losses.

The control of crosstalk [7] is one of the major problems in the application of carrier to open-wire lines. On short lines where only a

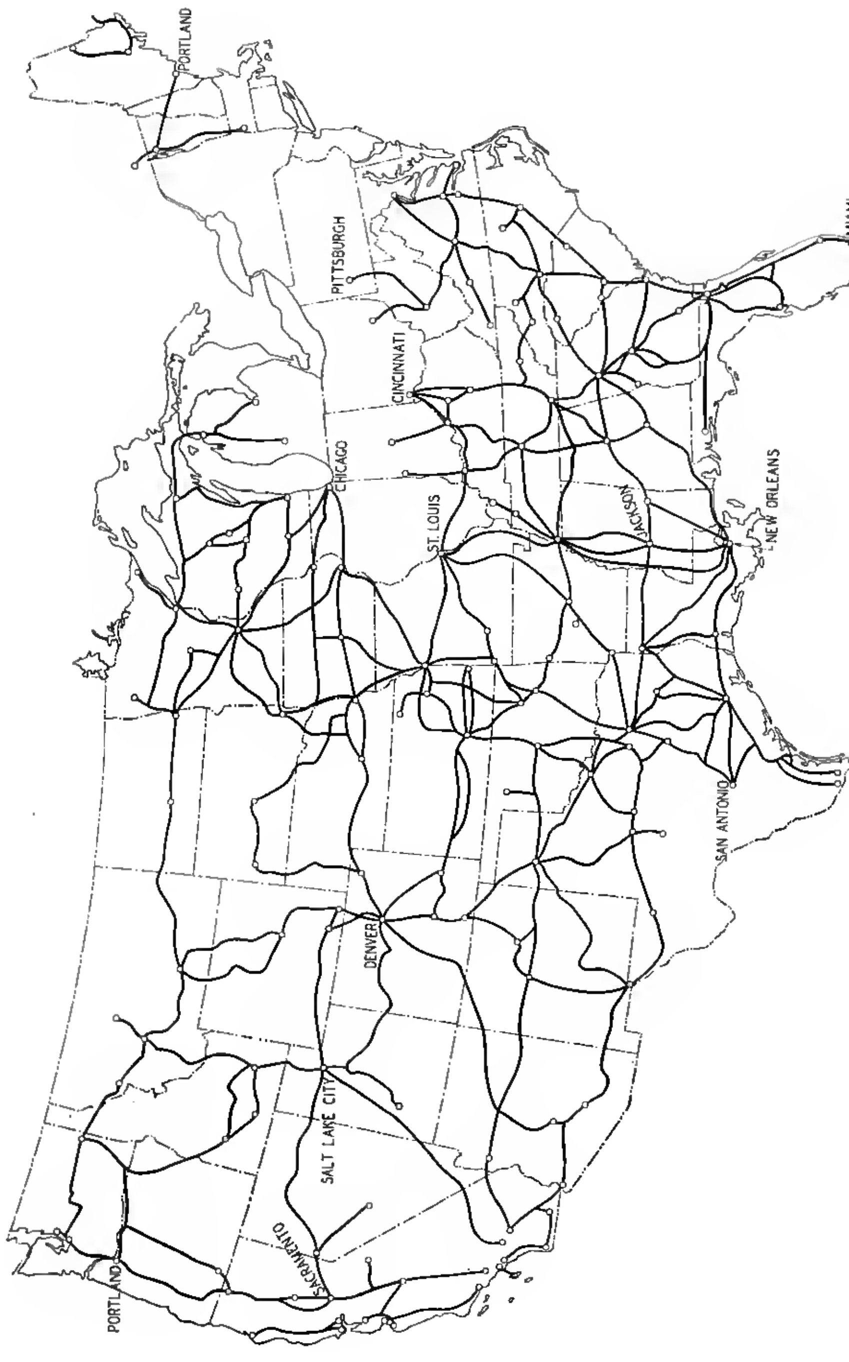

Fig. 19—Bell Telephone System routes on which Type C carrier telephone systems are operated.

few systems are involved, the engineering solution may be quite different from that on a long line on which it is desired to operate many systems. Several different plans for transposing wires have been developed which can be applied with various pole line configurations so as to meet the necessary requirements in any practical case. The more recently constructed carrier lines have, in general, employed a spacing of 8 inches between the wires of a pair, with from 16 to 26 inches between horizontally adjacent pairs. Besides contributing to the crosstalk reduction, the closer spacing is also less susceptible to interference from outside sources, which is an advantage from a noise standpoint.

Attenuation characteristics [8] for typical eight-inch spaced pairs using the CS type of insulator are given in Fig. 18. Normal or dry weather characteristics are shown, together with the losses that are assumed for ordinary wet weather. Temperature changes also result in sizable transmission changes. It is also important to note that the losses when the wires are coated with sleet or frost may go far beyond those indicated for the wet weather condition.

Conclusion

The widespread use that has been made of the Type C system up to this time is pictured in Fig. 19, which shows the routes in the Bell System over which systems are now operating. The new design with its lower costs, improved performance and greater flexibility should find increased application not only on these routes but on shorter lines on which the system has hitherto not been economical.

References

1. "Carrier Systems on Long Distance Telephone Lines," H. A. Affel, C. S. Demarest and C. W. Green, *Bell Sys. Tech. Jour.*, volume 7, July 1928, pages 564–629; *A.I.E.E. Transactions*, volume 47, October 1928, pages 1360–1386.
2. "Cable Carrier Telephone Terminals," R. W. Chesnut, L. M. Ilgenfritz and A. Kenner, *Bell Sys. Tech. Jour.*, volume 17, Jan. 1938, pages 106–124; *Electrical Engineering* (*A.I.E.E. Transactions*), volume 57, May 1938, pages 237–244.
3. "Carrier Telephone System for Short Toll Circuits," H. S. Black, M. L. Almquist and L. M. Ilgenfritz, *Electrical Engineering* (*A.I.E.E. Transactions*), volume 48, January 1929, pages 117–140.
4. "A New Single-Channel Carrier Telephone System," H. J. Fisher, M. L. Almquist and R. H. Mills, *Bell Sys. Tech. Jour.*, volume 17, January 1938, pages 162–183; *Electrical Engineering* (*A.I.E.E. Transactions*), volume 57, January 1938, pages 25–33.
5. "Copper-Oxide Modulators," R. S. Caruthers, Presented at Winter Convention of A.I.E.E., January 1939.
6. "Stabilized Feedback Amplifiers," H. S. Black, *Bell Sys. Tech. Jour.*, volume 13, January 1934, pages 1–18; *Electrical Engineering*, volume 53, January 1934, pages 114–120.
7. "Open-Wire Crosstalk," A. G. Chapman, *Bell Sys. Tech. Jour.*, volume 13, January 1934, pages 19–58; April 1934, pages 195–238.
8. "The Transmission Characteristics of Open-Wire Telephone Lines," E. I. Green, *Bell Sys. Tech. Jour.*, volume 9, October 1930, pages 730–759; *Electrical Engineering* (*A.I.E.E. Transactions*), volume 49, October 1930, pages 1524–1535.